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Integrated Logistics System for Indigenous Fighter Aircraft Development Program

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Abstract

Logistics Support plays an important role during development and utilization of a fighter aircraft. In the past, the logistics support activities had been mainly managed through paper based solutions. The shift to a computer based logistics support system assisted in quick analysis of the logistics record for supportability assessment and plan for alternatives. During the same time, the evolution of Product Lifecycle Management (PLM) solutions provided framework for exchange of engineering knowledge through effective configuration control, facilitating reduction in development/induction lead time. The need to reduce the developmental cycle time and the total cost including maintenance and support, and enhance the performance and reliability of the product led to the collaboration between PLM and logistics support systems. The PLM systems were extended to knit the engineering knowledge closely with the knowledge of logistics support, bringing the total lifecycle of an aircraft under configuration management. The integrated approach, also termed as Integrated Logistics Support (ILS), helped to define the performance and reliability objectives in the early stages of the program for the development of a maintenance friendly fighter aircraft with necessary support in place. The increased operational reliability thus led to innovations in the military aircraft contracting. The recent past has been witness to a novel contracting methodology known as Performance Based Logistics (PBL). Under PBL contracting, the Mission Capable Rates are defined at the design phase itself, and the obligation to keep the equipment in the operation ready state, over its serviceable life, rests on the manufacturer.

This paper presents the requirements that must be considered for implementing ILS. Furthermore, the paper presents a conceptual PLM based enterprise framework that records failure data, analysis undertaken and the corresponding corrective actions. The suggested conceptual model has provisions to record the logistics support related data, i.e. Logistics Support Analysis Record (LSAR), in the format compliant with the standards followed worldwide. LSAR would draw its input from engineering activities as much as from logistics support activities. A systematic and comprehensive analytical study, i.e. Logistics Support Analysis (LSA), can be conducted on an iterative basis on the LSAR data, through all lifecycle phases of the product development to achieve the laid down availability and maintainability objectives. The proposed ILS will allow the subject experts in the areas of design, manufacturing, maintenance planning, maintenance execution, provisioning, support equipment and personnel training to

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give their inputs throughout product development. The system shall facilitate assessment of the Life Support Cost (LSC) at the early phase of the program and streamline the logistics and spares required to support the product till the end of its serviceable life.

Keywords: ILS; LSA; LSC; FRACAS; PBL; Reliability & Maintainability, Fighter Aircraft.

1. Background

The introduction of PLM in the Aerospace & Defence (A&D) industry brought all stakeholders on a collaborative platform. It heralds an era of close coordination that had never been seen before and that yielded better design, reducing lead time and resources required. The PLM framework enabled the designers to leverage the state-of-the-art technologies viz. Digital Mock Up (DMU), tolerance stack up analysis and build sequencing effectively. There have been concerted efforts to bring the logistics support under the ambit of PLM to establish digital thread across the lifecycle till the product phase out. The logistics support activities that had been previously managed through proprietary solutions were based on inputs from the product development teams, allowing analysis of the required logistics support, supportability assessment and plan for alternatives. The birth of ILS approach brought other stakeholders also for planning of the logistics requirements at the early stages of the product development. The following two major components of PLM framework were instrumental in bringing all business functions into a single change process that can effectively drive information both upstream and downstream to provide effective lifecycle management.

1.1. Configuration Management (CM)

CM is a means through which integrity and continuity of the design, systems engineering and supportability are recorded, communicated and controlled. It results in complete audit traceability of decisions and design modifications, leading improvements in the change management by enabling change processes to include all affected organizations. CM includes the evaluation of all change requests, change proposals and their subsequent approval or disapproval, involving appropriate levels within the organisation of the customer and the developer for the project. It ensures that no change gets implemented without due consideration of its effect on the baselines, including logistics impact, costs, schedules, performance, or interface with any associate companies etc.

1.2. Concurrent Engineering

PLM helped to improve the logistics support data creation by directly linking it with part and product data. PLM made available full product views across product engineering, logistics, manufacturing and sustainment, facilitating better impact planning and improving the customer responsiveness by linking the logistics support data to the latest engineering modifications. The single source of product and process knowledge, for all lifecycle disciplines, on a collaborative platform of PLM aided in improved productivity and logistics support data integrity.

Nomenclature

A&D	Aerospace & Defence
CAMMS	Computerized Aircraft Maintenance Management System
CM	Configuration Management
CMRS	Calibration Measurement Requirement Summary
CSDB	Common Source Data Base
DDPMAS	Design, Development and Production of Military Aircraft and Airborne Stores
DMU	Digital Mock Up
FMECA	Failure Mode Effect & Criticality Analysis
FRACAS	Failure Reporting Analysis and Corrective Action System
ILS	Integrated Logistics Support
LCC	Life Cycle Cost

LOR	Level of Repair
LORA	Level of Repair Analysis
LSA	Logistics Support Analysis
LSAR	Logistics Support Analysis Record
LSC	Life Support Cost
OEM	Original Equipment Manufacturer
PBL	Performance Based Logistics
PHST	Packing, Handling, Storage and Transportation
PLCS	Product Life Cycle Support
PLM	Product Lifecycle Management
R&M	Reliability & Maintainability
RBOM	Reliability-Bill-of-Material
RCM	Reliability Centered Maintenance
SERD	Support Equipment Recommendation Data
SMA	Scheduled Maintenance Analysis
XML	Standard Generalized Markup Language

2. Integrated Logistics Support (ILS)

ILS is an integrated and iterative process for developing material and support strategy, guiding the system engineering process to quantify and lower life cycle cost. By leveraging the existing resources, ILS optimises the functional support while decreasing the logistics footprint, making the system support friendly. ILS provides a

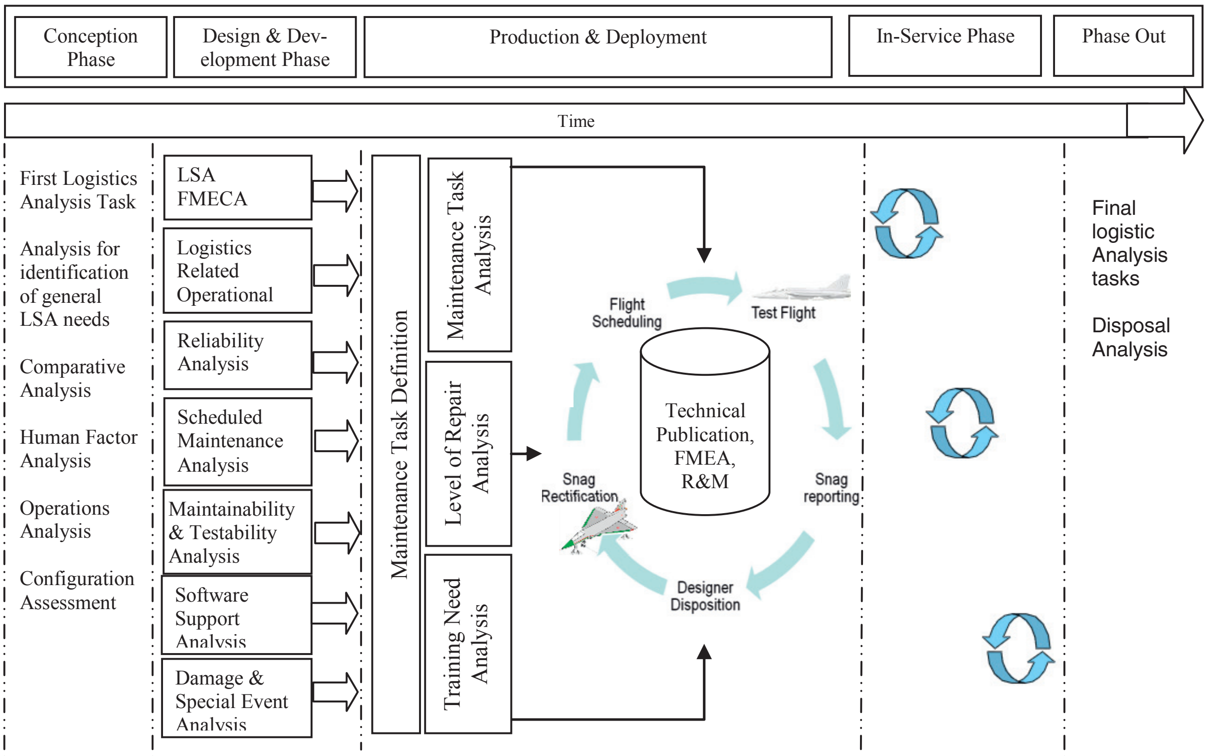

Figure 1 Logistics Support Analysis Activities over the lifecycle of the aircraft [6]

framework for the integrated evolution of technical manuals and required logistics for better product availability and sustenance. It ensures that the maintenance man hours per flight hour are within the acceptable limits.

LSA is a subset of ILS that provides the framework for monitoring and controlling the systematic development and execution of the ILS program. LSA is a disciplined and live exercise that starts from the conceptual phase and evolves throughout the lifecycle of the aircraft. It is a comprehensive analytical process that integrates system design and support system requirements, maintaining the history of the supportability decisions for the product development. It helps in establishing a direct relationship between logistic-related design parameters such as reliability, maintainability and availability; and support resource requirements [4]. The use of LSA approach enforces the developer from the conception through disposal of the product to consider all elements of the product life cycle such as cost, schedule, performance, supportability, quality and user requirements. Combined with PLM, the LSA plays a deciding role in influencing the design so that both the product and the support can be provided at an affordable cost. Figure 1 describes various analyses that can be carried out over the lifecycle of the equipment for defining and maintaining the LSA record. In the early phase of a program, the logistic activities, as shown in figure 1, can be limited to the ones that only require a low level of information. Section 3 & 4 highlight the LSA activities that can be performed during "design and development" and "production and deployment" phase respectively. The standards that need to be complied with for implementing ILS are discussed in Section 5. Section 6 describes the PBL, which is a new trend in contracting and made possible by the ILS.

3. ILS activities during Design & Development Phase

Any failure identified by analysis during design and development saves a huge cost by weaning out the possibility of a failure in the field trials or in-service. Thus, analysis plays a critical role as it helps to identify a failure in the early stages of the product development when the cost associated with the remedial action is minimal. As shown in figure 1, the following analysis/processes should be established during the design phase for implementing LSA.

3.1. LSA FMEA and design-oriented FMECA

While the objective of a Failure Mode Effect & Criticality Analysis (FMECA) is to identify all modes of failure within a system design, its first purpose is the early identification of all catastrophic and failure possibilities so they can be eliminated or minimized through design correction at the earliest possible time. Although FMECA is an essential reliability task for design activities, it also provides data for maintainability, maintenance or safety analysis, availability analysis, logistics support analysis, failure detection and fault isolation. LSA FMEA is derived from FMECA and is used for Level of Repair Analysis (LORA), Reliability Centered Maintenance (RCM) and Scheduled Maintenance Analysis (SMA). Because the maintenance activities may not focus on the individual components but on replaceable or repairable units, which maybe located at a higher level of breakdown than that of individual components, LSA FMEA is generally coincident with, but not identical to, design oriented FMECA.

3.2. Logistics related Operational analysis

The identification of logistics relevant operations, including the requirements concerning personnel, support equipment, consumables, spare parts, facilities and required training, is an important area of logistics analysis tasks. The logistics related operational analysis helps to identify the tasks related to servicing, Packing, Handling, Storage and Transportation (PHST); mooring, shoring, disposal and recycling, and other logistics related operations.

3.3. Failure studies and Reliability Assessment

The objective of failure studies is to get insight into the system parameters that affect the system performance. The failure data as recorded in Failure Reporting Analysis and Corrective Action System (FRACAS) represents the "real-world" experience of actual failures and their consequences. It is compared against FMECA, which represents the failures modes anticipated by the designers during initial phases of development. Significant differences between the FMECA and FRACAS are cause for reassessment of the design and may lead to engineering changes, Reliability & Maintainability (R&M) corrections or updates to the technical manuals [2, 5]. Authors [7] & [8] proposed PLM based Computerized Aircraft Maintenance Management System (CAMMS) that shall act as vault for provisioning, logistics, failure and corrective action and other product related data generated during the field trials. This supposed system shall encapsulate FRACAS framework, enabling correlation to be made between predicted R&M data and actual performance R&M data. The reliability assessment shall help in reckoning the individual component's performance, which shall add up to system and aircraft performance. Through the R&M studies, a Reliability-Bill-of-Material (RBOM) can be formed considering the failures and its cascading effects. The FMECA and FRACAS can be utilized to interlink the failures and the reliability issues to the different components in the product tree. This shall aid in troubleshooting the failure and predicting the next level of failures, the cascading/end effects for each failure mode and recommended actions to mitigate their effect. This information shall reveal when there are potential reliability, maintainability and logistical hot spots and extends an opportunity for continuous process improvement through lean or six sigma methodologies.

3.4. Scheduled Maintenance Analysis (SMA)

SMA involves detailed analysis of potential failures and damages, their effects and causes. SMA analyses the identified potential scheduled maintenance tasks to determine the maintenance intervals or thresholds. It consists of activities that are replace, repair or overhaul such as the replacement of components after a specified period of use, scheduled inspections after specific intervals/thresholds and activities following special events. SMA documented in international specification such as S4000M, or RCM are grouped into three general areas: i) System and power plant analysis, ii) Structural analysis; & iii) Zonal analysis. Each of these analysis methods has its own methodology and own procedures to determine scheduled/preventive maintenance tasks and the corresponding intervals.

3.5. Maintainability & Testability Analysis

Figure 2 shows the different steps involved to achieve the Testability Analysis. Any corrective maintenance for a test capable items is dependent on the detectability of the failure to be corrected. If a failure cannot be verified by any test procedure, the corresponding repair task cannot be performed. In addition to these aspects, it is necessary to be able to perform a functionality test of an item after repair. The failure detectability and its verification are the important factors for maintenance tasks definition. All LSA items should be analysed for testability

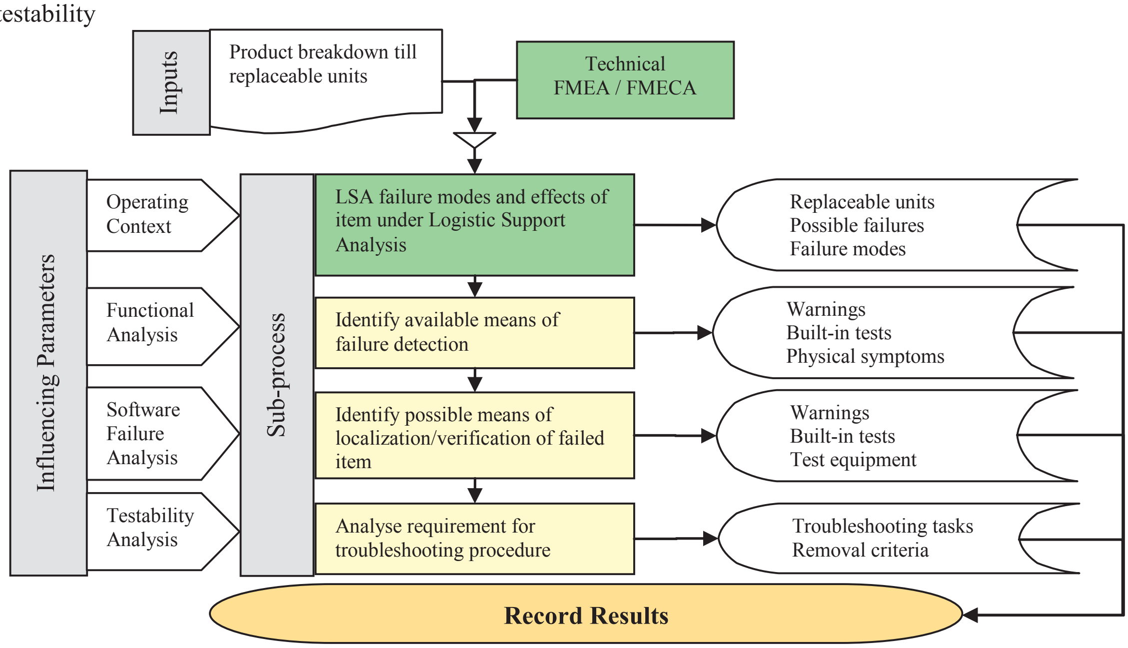

Figure 2 Steps involved in Testability Analysis [6]

3.6. Software support analysis

Each items containing user loadable data/software must be analysed with regards to loading, deloading, transportation, achieving and documentation of existing SW releases. This covers maintenance and servicing tasks applicable for maintenance of hardware containing user loadable data/software, operational software/data required for flight preparation, and software support in order to update items with new user loadable software releases.

3.7. Damage & Special Event Analysis

Damages are special events for which a prediction of criticality or extent cannot be given for every case. Nevertheless, it is useful to identify classes of damages, which can be maintained in the same way or which can be detected in the same way. Because reliability values concerning damages are not normally available, general quantitative statements are generally not possible. Only with the help of statistical evaluations it is possible to get a prediction of the required effort resulting from damages.

In addition to the occurrence of damages, which are a type of special event, other events can have an impact on the maintenance concept for an item under analysis or on the product. In order to guarantee the proper functionality, identification and documentation of probable special events that require special maintenance tasks is required. Also, the required maintenance tasks must be described and documented, including information concerning required resources like personnel, material or software, within a logistic database. Some examples of special events that required maintenance tasks include: i) Exceeding temperature limitations, ii) Exceeding mechanical load limits (e.g. over torque), iii) Exceeding maximum allowable speed, iv) Operation in salt-laden atmosphere, v) Lightning strike, vi) Hard landing of an aircraft, vii) Collision with external object (e.g. bird strike)

4. ILS activities During Production & Deployment Phase

The data captured during the field trials, in accordance to MIL-STD-1533B, is of immense value to both designers and shop technicians. It is rich in information related to fault observed, their diagnosis, corrective action taken, provisioning of spares and logistics. The data can be utilized to validate the analysis done for the LSA activities or enhance upon it. Also, the data can be utilized to do the sensitivity analysis on the baseline processes established for LSA in the design phase. As shown in figure 3, the failure report and the corrective action data as recorded in the FRACAS framework during field trials is utilized to update the performance/R&M data as calculated during the

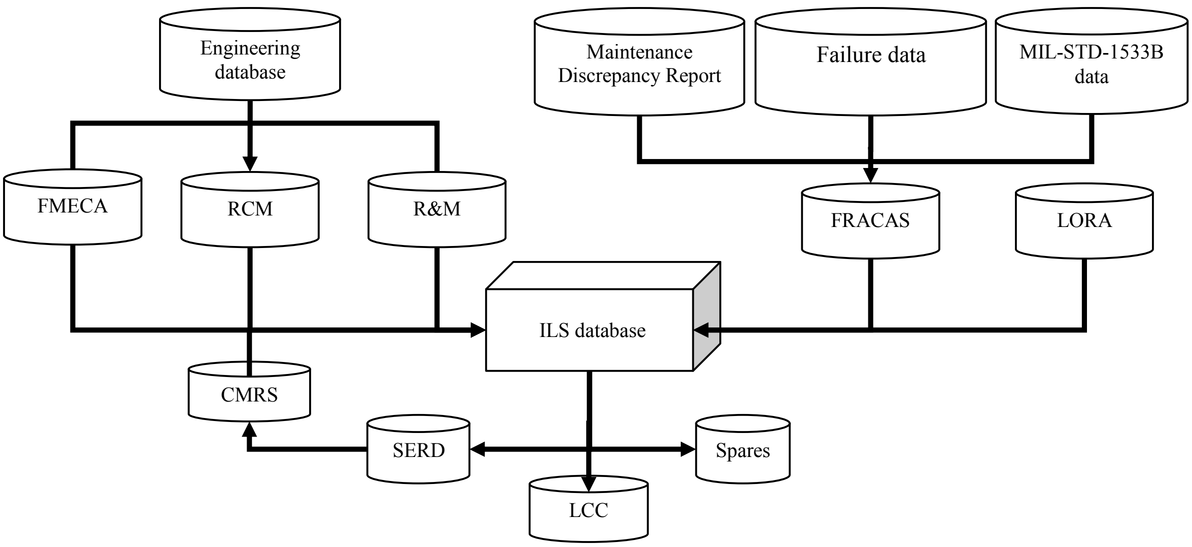

Figure 3 Logistics Support Analysis [10]

design phase. The data is useful for carrying out LORA, establishing Support Equipment Recommendation Data (SERD), creating Calibration Measurement Requirement Summary (CMRS) and Life Cycle Cost (LCC). The vast repository of data build up in the ILS program is used to produce the training, provisioning and technical publications required to support the system or equipment. The initial spares, replenishment spares and cost required for sustaining the product for a given operating scenario and period of performance can be calculated by the Life Cycle Costing procedures, which derive their data from ILS database. This further can be used to conduct sensitivity analysis to reduce the total support cost by optimising spares mix and highlight the items where reliability improvement would produce the greatest cost savings. The section below discusses various LSA activities that can be carried out based on the field data.

4.1. Maintenance task analysis

Maintenance Task Analysis is one of the central analysis activities within the LSA process. Here, the identified maintenance tasks (both scheduled and unscheduled) are detailed with all required information viz. i) Documentation of general task information such as preconditions for task performance, training requirements or criticality information, ii) Assignment of maintenance tasks to the identified events, iii) Rough task description (sequence of subtask), iv) Identification of related logistics resource requirements (e.g. personnel, support equipment, spares, facilities, software), v) Time estimations, vi) Calculation of task frequencies, vii) Consideration of required pre- and post- tasks (e.g. test, fault location, gaining access)

4.2. Training Need Analysis

The identification of training requirements concerning maintenance activities can be derived from the maintenance tasks documented in the LSA database. Within this analysis, it must be decided whether a task requires special training or not. If training is required, it must be determined how the training can be applied most effectively. This process can be supported with the help of the content of the LSA database concerning the identified tasks.

4.3. Level of Repair Analysis

For a complex engineering system containing thousands of assemblies, sub-assemblies, components, organized into several levels of indenture and with a number of possible repair decisions, the Level Of Repair (LOR) studies help to determine an optimal provision of repair and maintenance facilities to minimize overall system. Based on personnel expertise, the initial LOR can be established. The improvement on the baseline LOR decisions can be taken up as the feedback is accrued over the lifecycle of the product. Though the process is generally useful in establishing the LOR it results in less collaboration from the engineering teams and thus escalation of the costs.

LORA, as defined in MIL STD 1390C [3], is an analytical methodology used to determine when an item will be replaced, repaired, or discarded based on cost considerations and operational readiness requirements. It determines where each required maintenance action will be performed, the physical resources that must be available to support performance of maintenance, and the support infrastructure required to sustain the system throughout its operational life. The LORA can be applied on the baseline indenture levels or on initial LSA components. A sensitivity analysis can be performed on various cost significant parameters. The results of the various sensitivity runs will indicate whether the maintenance solution from the baseline run is stable or not. The output of the sensitivity analyses can be used as a baseline to establish a preliminary maintenance solution and the indenture level for the LSA components. An example of a maintenance strategy is given below, based on three levels of maintenance, which indicates the capability of personnel, availability of special facilities, time limits and the environmental conditions to be assumed in determining the functions to be accomplished at each maintenance level.

4.3.1 Organizational maintenance / Operational Level

Organizational or O-level maintenance is done at the organizational unit level, for example by a single maintenance squadron, and is typically optimised for quick turn-around, to enhance operational availability.

Maintenance at this level typically consists of preventive maintenance, corrective maintenance i.e. removal and replacement of the unserviceable LRUs, simple modifications, usage preparation and role changes, pre-and post-flight inspections, functional checks, trouble shooting, loading of software and data retrieval.

4.3.2 Intermediate maintenance

Intermediate or I-level maintenance is done in specialized facilities, typically allocated to multiple operating units residing at a common operating location, that are capable of accommodating the maintenance tasks that could include special equipment or specialized workshops and will be performed by appropriately trained and specialized personnel. I-level maintenance is of more specialized nature and allows for thorough and time-consuming diagnostic testing and repair procedures, usually in support of failed items removed at the O-level of repair. Test equipment is more common at this level of repair, and is used to automate many test procedures. The activities at I-level include repairs down to module and subassembly level, moderate structural repairs, major scheduled inspections, moderate modifications, technical assistance to the O-level organisation, software servicing concerning engineering data, preservation of complete product, corrective and preventive maintenance and specific maintenance activities that will be performed both on product, and off product.

4.3.3 Depot-level maintenance

Depot or D-level maintenance typically is done in highly specialized, or at Original Equipment Manufacturer (OEM) facilities and by appropriately trained and specialized personnel. Equipped with extensive diagnostic equipment and possibly even manufacturing capabilities, these sites are capable of executing repairs down to full overhaul, repairs requiring special skills or support equipment, major structural repairs, major scheduled inspections, major modifications to improve the design and/or operational activities, technical assistance to the O-level and I-level organizations, software modification or preservation of the complete product. The D-level activities as the highest maintenance level can also be subdivided into two or more levels. This can be used when required to clearly separate the user operated activities from the OEM, assuring a maximum autonomy for the user organizations.

As the military aircraft undergoes constant modifications for tactical measures and to maintain the combat strength, it leads to design modifications and can set off adjustments to the logistics data as well. The in-service data assists in making the required corrections to the LSA data. This can be through updates to the FMECA, adjustments to the maintenance schedules, update and revision to maintenance tasks. Also, the in-service data helps in accounting for any new failures that could not be anticipated/simulated in the earlier phases. The analyses described in section 3 & 4 can be judiciously taken up for accommodating the modifications to the LSA activities.

LSA plays a vital role till the end of lifecycle of a product. The requirements for disposal of the product are implemented into the design from the very beginning of a development program. The logic to determine the disposal process, disposal tasks, and support resources required, starts with the disposal analysis and needs to be tailored for the program.

5. Different Standards required to implement the ILS

The lifecycle of military aircraft can be over 50 years, much higher than any other commercial product lifecycle. The operating and support costs of the military equipments make up about 60-70 percent of a weapon system’s total lifecycle costs. An extended lifecycle implies that the system will go through constant change to adapt to the war-fighting environment. The challenge is to support the equipments after production while reducing sustainability costs [9]. In compliance with the standards and protocols that allow legacy systems as well as future technological innovations to interoperate seamlessly, an ILS can achieve the objective as stated above. Figure 4 shows the different specifications, described below in brief, that needs to be followed while establishing the PLM enabled logistics support system.

S1000D: It is an international specification for technical publications. It uses international standards such as the Standard Generalized Markup Language (XML) and Computer Graphics Metafile for the production and use of electronic documentation. S1000D is organized in a modular approach based on the Common Source Data Base (CSDB) principle for data creation and storage.

S2000M: International publication for material management. This is a standard for spares and provisioning. S2000M defines the process and provides the mechanism for communicating and exchanging provisioning data between contractors, partners and government agencies. This information is a key component of the required ILS data set.

S4000M: International procedure handbook for the development of scheduled maintenance programs for military aircraft.

S3000L: It is a logistics handbook for performing LSA based on Product Life Cycle Support (PLCS) and specifically tailored for A&D.

S5000F: It is the specification for operational and maintenance data feedback. The data feed from in-service operations and maintenance forms the basis for the empirical validation, update and correction of the theoretical, calculated and predicted values that have been established within the LSA activities.

The different standards in an ILS program intercommunicate among each other in compliance with DEX1A&D and DEX3A&D, the standard for exchange of product breakdown and task specification.

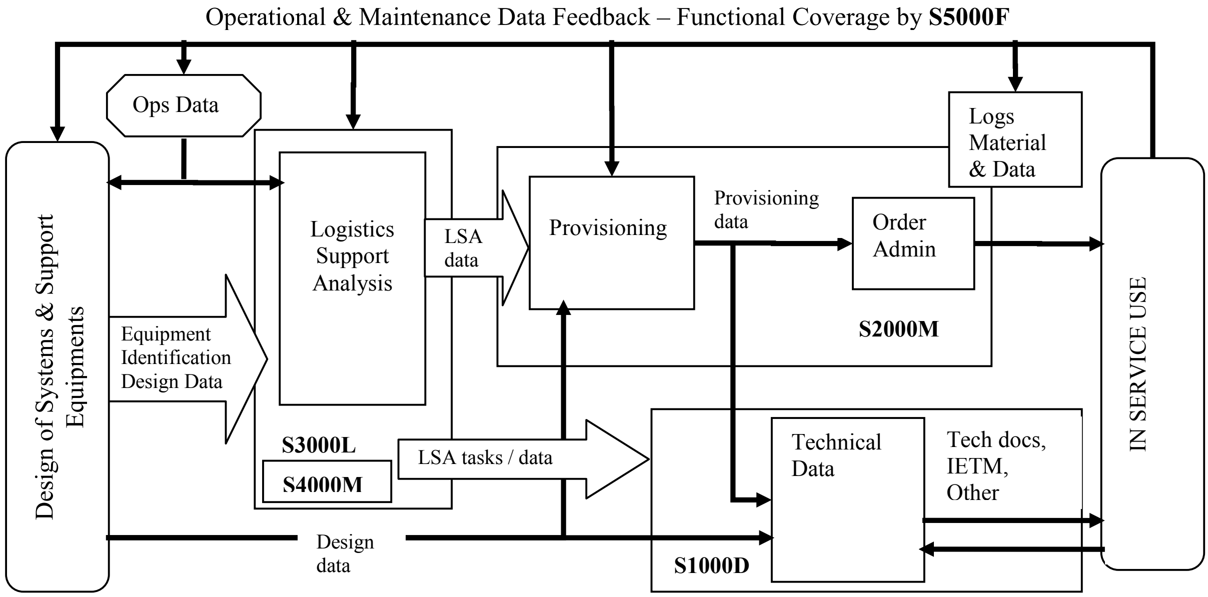

Figure 4 Different standards for the implementation of ILS [5]

6. Conclusion

The A&D industry is highly competitive and the application of ILS tools and processes can be a product differentiator, aiding in lowering the sustainment costs and achieving the performance goals. One of the recent innovations in acquisition of military aircraft, enabled by ILS, has been PBL. In a PBL based contract the mission capable rates are defined at the design phase itself and the obligation to keep the fighter aircraft in war ready condition rests on the manufacturer. It is a strategy for product support that employs the purchase of support as an integrated, affordable performance package designed to optimise system readiness. PBL improves the operational capability while reducing cost and deployment footprint [1]. The intent of PBL is to form a long-term partnership between industry and the government early in the development of a system or product that is focused on enhancing fighter aircraft capability over the life of the system or product. PBL would require an OEM to commit to a long-term fixed price contract to produce and support the fighter aircraft over its lifecycle.

ILS as a practice has evolved over decades in western world. India has emerged as a promising candidate in the military aircraft domain. To reap the benefits out of its indigenous programs that the country has assiduously pursued for the last many decades, it has to adopt the practices like ILS. As the country targets to export the indigenous aircraft, it becomes imperative to project the cost of operating the equipment over its lifecycle. In this direction, the indigenous military aircraft program needs to define a maintenance concept based on the operational requirements including viz. major functions accomplished at each level of maintenance, basic support policies and effectiveness factors such as maintenance labour hour per flight hour. ILS will enable an accurate estimation of the total lifecycle cost of an aircraft, the cost associated with level of provisioning, maintenance and logistics requirements over the lifecycle of an military aircraft. Further, it will aid in conducting studies for different operational scenarios to evaluate the system performance, identify maintainability and availability improvement areas and evaluate alternative design solutions for the upcoming projects. ILS as defined in the paper is required for the indigenous program for achieving the said objectives. Design, Development and Production of Military Aircraft and Airborne Stores (DDPMAS), which is the bible that is religiously referred to for any military equipment acquisition program in India, is required to be augmented with the standards, or equivalent standards, as discussed in paper for implementation of ILS. Over the time as different organizations adapt to these standards, an ecosystem conducive for “Design for Maintainability” will emerge, facilitating introduction of concepts like PBL.

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